Reports on the Marine Biology of the Sudanese Red Sea.—IV. The Recent History of the Coral Reefs of the Mid-West Shores of the Red Sea.

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(Plates 1 & 4.)

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Contents.

General Description of the Coast.

The remarkable parallelism of the sides of the Red Sea "Rift Valley" is varied on the west by three prominent points, Ras Benas, Ras Elba, and Ras Rawaya (see Map, fig. 1, p. 6). Between Ras Rawaya and Suakim the coast-line is, in the main, very regular, but it bends eastward again at Trinkitat, and is broken by some large bays about Agig.

As is well known, the sides of this trough are composed of ranges of mountains of granite and other crystalline rocks remarkable for their wild and jagged shapes and utter barrenness, while the actual coast is a low plain. Except for its seaward border, which is invariably of elevated coral, the surface of this plain is composed of alluvial gravel and sand from the hills *. In certain localities the plain is divided by ranges of low hills, somtimes capped with coral, which rise in the midst of the plain and run parallel, more or less, to both sea-coast and mountains †.

This is the structure of the whole Red Sea coast at least as far south as latitude 18° 10′ N., with the exception of the northern part of the Gulf of Suez, which is totally different ‡.

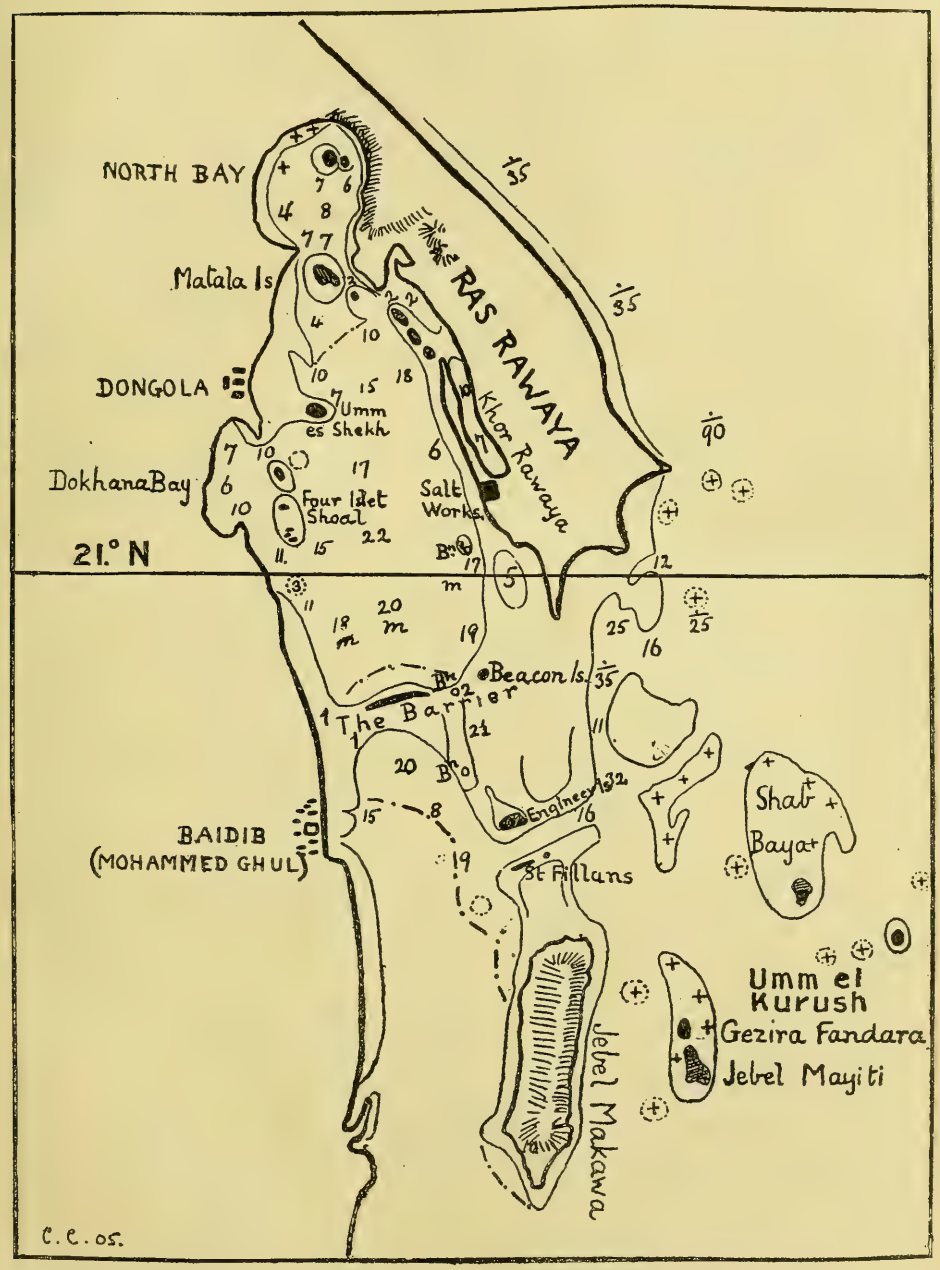
A very striking feature of this coast is the large number of canal-like bays or "Khors" which run into the coast-plain. Reference to the map on p. 6 shows nine large examples in the space of only 40 miles just north of Rawaya,

* Artesian borings made by the Public Works Department of the Sudan Government two miles inland from Port Sudan show that the same materials extend downwards as far as the borings went, *i. e.* to a depth of at least 1000 metres.

† As these hills are of special interest I give an enumeration of them and description of those I have climbed in a postscript (p. 27).

‡ The crystalline hills are here absent, the coast being formed of high, flat-topped, wall-like hills of Cretaceous limestone which rise almost directly from the sea.

FIG. 2.



MAP OF DONGOLA AND ITS VICINITY.

and the Chart of Suakim Harbour gives the features of a typical specimen. The characteristics more or less prominently developed in all are :—

(1) Canal-like outline.
(2) Crossed branches running N. & S. and E. & W.
(3) A nearly uniform depth gently shoaling as one passes landwards.
(4) A flat bottom of coral-mud.
(5) Precipitous sides of growing reef below sea-level and cliffs above. The latter are of course the height of the neighbouring plain, generally 2 feet or so in Suakim Harbour, or up to 12 feet in Khor Shinab.

The late Mr. Barron, who was Geologist to the Sudan Government, explains these formations as resulting from two systems of faults at right angles to one another. The almost rainless climate, the absence of very strong tidal currents, and the protection afforded by growing coral, have allowed the above-mentioned characteristic and almost bizarre features to remain, whereas in the corresponding structures on the equatorial coasts of East Africa the erosion of powerful tidal currents and of freshwater streams has, in most cases, widened creeks into bays and broken down their vertical sides into shelving shores.

The Red Sea has an evil reputation with navigators on account of the number and complexity of its coral-reefs and the presence, in certain areas, of that especial horror, the coral pinnacle which rises out of deep blue water to just under the surface. The reefs may be divided into :—

(*a*) Fringing reefs along the coast and round islands.
(*b*) A Barrier system, which is especially typically developed between 19° N. and 24° N.
(*c*) Scattered reefs, including some of Atoll form.

The climate is noted for an extreme aridity, which is however not so complete in the southern part of the coast as in the northern. Among the hills furious rain-storms are frequent in August and winter, which flood the valleys for a few hours at a time in the way described by travellers in the Sinai Peninsula, and by Egyptian Survey Department officials for the desert bordering the Gulf of Suez *. These conditions are of course the best possible for the conveyance of the large quantities of detritus which have formed the great alluvial maritime plain.

The tides have been referred to in the Narrative (p. 3), where it is stated that the middle part of the Red Sea is practically tideless. There are, however, variations of level of two feet or thereabouts which occur almost daily, but their occurrence is subject to no fixed rule. The rise or fall may be fairly regular for several days, high water being at nearly the same time each day, then it may remain continuously low or continuously high for a short period. Occasionally the water may sink to a foot below its lowest normal

* Barron & Hume : "Topography and Geology of the Eastern Desert of Egypt, Central portion," issued by the Survey Department, Public Works Ministry, p. 282.

level and remain down for one or more days. Further, the mean level is about three feet lower in summer than in winter.

It is found that there is a true tide of a few inches, but that this is swamped by the greater changes of level induced by changes of barometric pressure. The "tides" are therefore quite irregular and cannot be predicted.

My own observations have been made daily for about six months at Dongola, where, owing to its position near the head of a very long bay, the effect of the strength and direction of the winds is very marked, but even there the wind is not the only factor in producing changes of level.

The difference in the level of the whole of the Red Sea in the winter and summer is a result of the monsoons in the Indian Ocean. The total difference between highest water in winter and lowest in summer is about six feet.

Causes of the Forms of the Present Reef System.

The theory advanced is that—(i.) As the region is one where considerable upward movement (at least 500 feet) has occurred since modern reefs began in the Sea, and where elevation is still in progress, Darwin's subsidence theory cannot be called into account for the existence of the barrier reefs at a distance from land and separated from it by deep water, or of the atoll forms of certain reefs. (ii.) The relations between elevated and still living reefs show that the foundations of both are ranges of sandstone hills partly below sea-level. (iii.) The forms of the reefs are due to the balance of aggrading over degrading agents, the former being the growth of coral, nullipores, &c., and the latter the corrosive action of the sea and the rotting caused by boring organisms, &c.

A note on the probable cause of the changes effected after the upheaval of a coral-reef, whereby it takes on the hardness, homogeneity, and crystalline structure characteristic of "Coral-Rag," is appended.

Evidences of Elevation.

The existence of the coast-plain and its breadth, which on the Sudan coast averages five miles, are against any considerable movement of depression during its formation. The raised reefs indicate upward movements of 1500 feet or more, and more recent changes are recorded as raised beaches and old erosion-lines or cliffs, of which examples are found throughout the length of the Sudan coast.

At Agig, a mile inland, but only a few feet above the sea, is a raised beach in the form of a long ridge of rolled pebbles of crystalline rock corresponding to that of coral-fragments which borders the present shore. Both are surmounted by a line of graves, the seashore having been, apparently, a favourite place of sepulture through all ages. Even the design of the graves

remains much the same, except that the modern stones are but a fraction of the size of the monoliths of the old days.

Some particularly conspicuous cases of raised erosion-lines on cliffs are to be seen at Tella Tella Suraya Island in the south, and on Haysoit Island in Khor Dongonab in the north. These are treble lines, the modern one at sea-level, and two others at points 3 and 5 feet above this. A single raised line may be seen in the harbours of Port Sudan and Suakim. The larger of the islets of the landlocked North Bay of Khor Dongonab is of limestone, and has a line of undermined cliffs along its northern, or exposed, side, the base of which is now some feet above sea-level and separated from the shore by a stretch of sand about a hundred yards wide, and covered with the xerophytic plants usually found on these dry sandy islets. One should note that the higher cliffs, seen from a distance, appear to show lines of undermining in some cases, but that these, on a nearer view, turn out to be the results of subaerial denudation. The hills are formed of horizontal strata which are in some cases alternately hard and soft, and the latter, standing out from the general level, simulate the overhanging part of a marine cliff. But in these selected cases, as in that described below, the smaller details of wave-action are preserved so that the former, lower, position of the cliff is evident beyond doubt.

The horizontal position of the strata shows that the elevation of the limestone from the sea has been effected in a regular manner ; but evidence of the steadiness of this movement is given by the occurrence everywhere of elevated coral colonies, which are in the same position exactly, relatively to the surrounding rock, as that in which they once grew in the sea. Such colonies may be of quite delicate branched species, and good examples of such are exposed in the trench which surrounds one of the blockhouses which once protected Suakim from the Dervishes, but generally the fact is more easily made out in the case of massive species. Very conspicuous examples were seen on Tella Tella Suraya, an island of which the Admiralty ' Pilot Book ' notes that it is distinguished by the presence of many cairns of stones upon its highest parts. The island is about 40 feet high and surrounded by cliffs, mostly of rather loose coral-fragments and abundant shells &c. of present-day species. The "cairns" on the level summit of these cliffs are simply large hemispherical coral colonies which survive the weathering that has removed the surrounding softer material. Corals similarly situated are exposed in many places on these coasts, the summit of Jebel Têtâwib in Khor Dongonab bearing a particularly fine series. There would be no difficulty in identifying them as species at present living in the adjacent sea. The island is a miniature elevated atoll, the present bottom of the lagoon being just above the sea-level, and consisting of a flat sheet of mud, which was drying and slightly crusted with salt at the time of our visit, at the beginning of March. This depression is surrounded by high ground, its present communication with the sea being probably subterranean. The lagoon is bordered by bushes, of the species which live in

salt swamps, and about six feet above them are small cliffs which show very distinct marks of having been undermined by waves at a time when the lagoon was at a lower level and contained water. Above these the ground slopes steeply to the level of the summit of the cliffs.

For other elevations see the postscript on the sandstone coast-hills (p. 27).

Two sets of elevations have been shown to have occurred since reefs of modern corals began to be formed in the Red Sea: (i.) A major series up to at least 500 feet (Rawaya, Makawa, &c.). (ii.) Minor elevations which are very recent and are probably still going on. (Recent raised beaches and erosion-lines on the cliffs.)

The Living Reefs.

Fringing Reefs.

These reefs occur practically everywhere on the open coast and in the bays and "khors" except at their extreme landward ends. Their absence from parts of Khor Dongonab has been noted in the Narrative (p. 5). They are absent also from small lengths of the coast-line at Ras Baridi (noted by Darwin, on the east side of the sea) and from the shores of "Dokhana Bay" in Khor Dongonab. As in one or two similar cases in British East Africa, I can give no reasons for these omissions except in one case—the harbour of Dabadib, on the Sudan coast between Salak and Port Sudan. Here the coral-border to the coast-plain is almost entirely covered by a deposit of the very fine sand, derived from crystalline rocks, which at times of high winds causes thick "fogs" in the Red Sea. This fouls the water and prevents coral-growth in the immediate vicinity. Probably the case of "Dokhana Bay" is the same; the water certainly is muddy there, but I have not determined the origin of the mud, and in some cases, *e. g.* Suakim Harbour and especially the North Bay of Khor Dongonab, coral can flourish in very cloudy water *.

The shore-reef is broad where the coast is low: *e. g.*, at the entrance to Suakim Harbour, where it is but a foot or two above sea-level, the reef is $1\frac{1}{2}$ sea-miles broad, while at Port Sudan (Mersa Shêkh Barûd) the coast is 6 feet high and the reef only $\frac{3}{4}$ mile wide. This difference is obviously due to the lesser rate of erosion where fallen rock protects the base of the cliffs for a time against the sea. It is obvious that the formation of reef-flats by erosion is going on here just as on the Zanzibar coast, but that here it is impossible to determine what proportion of the total breadth attained is due to the cutting-down of the land and what to the addition due to recent coral-growth.

At a point just north of Mersa Abu Hamâma, at Dabadib, Mersa Fîjab, and some other points, the coral-limestone has been nearly completely removed, the shore being formed of the rolled grey pebbles of the alluvial

* Note added Sept. 1907.—Fresh water, flowing underground, enters the sea at Dabadib and "Dokhana Bay" nearly all the year round.

plain. That the greater part of the reef-surface was formed by the removal of elevated coral is conspicuously demonstrated, in the first case mentioned, by the presence of numerous isolated pillars and grotesque rocks of this material scattered over its landward portion, in the third by the presence of coral-rock islands; but at Dabadib, as already mentioned, only a narrow band of rock surface is visible at water-level.

Only narrow reefs are found below the comparatively high cliffs (30–40 feet) of the east side of the North Bay of Khor Dongonab. I attribute this to the reefs being sheltered from the prevailing winds, and consider it merely as a further indication of the importance of erosion as a factor in reef-formation on coral coasts.

The surface of the shore-reefs is generally sandy, but bare rock-patches occur, especially as a border to the growing edge. Stones are rare or quite absent except at the slightly raised seaward margin, where the remains of dead coral colonies are sometimes scattered. Such large and solid stones as those so plentifully scattered on the reef-edge in Zanzibar are, from the nature of the case, altogether absent from this area, which has been formed directly by growth of coral and nullipore *.

The raised edge consists of a gravel of broken coral well covered with nullipore. Outside this is a gentle slope of corals, generally stunted and accompanied by nullipore and alcyonarians (Xeniidæ), which extends to a depth of a fathom or so, after which is a precipitous slope of luxuriant corals reaching as far as we can see with the water-telescope, say to 10 fathoms or beyond.

There is generally a more or less regular boat-channel or series of pools of water a fathom or so deep, with numerous outlets to the open sea, some of which provide anchorages for sambûks (or "dhows" as they are called in Zanzibar).

In shallower water than that found generally off the shore-reefs the maximum depth at which coral grows luxuriantly decreases, for instance on the Shubuk boundary-reef, to be described later. A slope of mud with scattered corals is visible below the precipice of luxuriant growths. Similarly inside the harbours, where also the species of corals change, the delicately branched and fan-like forms, which are in the majority outside, give place to massive *Porites*, *Meandrina*, and so on. On this coast it is the massive genera which are characteristic of sheltered waters, not *vice versâ*.

The fringing-reef on the east side of Jebel Mayiti is also worthy of note. The island is a pyramidal hill, the east side being precipitous. From the summit one looks down upon a brown fringing-reef covered by a foot or two

* The stones found on the raised reef-edge of the Zanzibar coasts are the harder portions of the rock removed during the formation of the reef, which have been preserved in the way described in the paper (*loc. cit.*). The "negro-heads" of Pacific atolls probably have a similar origin.

of water, perhaps one hundred yards wide, and apparently of uniform structure throughout. Its clear-cut edge meets the blue-black deep sea directly, without the intervention of a patch of lighter colour anywhere, giving the most forcible impression of the edge of a fathomless abyss.

Scattered Reefs and the Shubuk Area.

It will be convenient in considering the remaining reefs to divide the coast into two sections—the first from Ras Benas to Suakim, the second from Suakim to the boundary with the Italian territory, Ras Kasar. The former is characterized by the presence of well-developed barrier systems and deep water close to all reefs; the latter by innumerable small scattered reefs and sand and coral islands (the Suakim archipelago) in comparatively shallow water and a shelving bottom, and, in the south, a comparatively slight development of recent coral-growth. The contrast is thus a very strongly marked one and very significant also*. One of these scattered islands, Tella Tella Suraya, has already been described.

The only other feature of interest in this neighbourhood is the Shubuk area, a hundred square miles of the most intricate passages among reefs, surrounded on the N.E. and E. sides by an unbroken reef similar to the ordinary fringing-reef of the shore, and on the S. and W. by the mainland. Most of the reefs enclosed are merely sandbanks capped with a fathom or so of growing coral, but on the more exposed N. and W. sides the coral goes deeper and, where not growing coral, the bottom is largely composed of dead fragments of coral, shells, &c.

The land hereabouts is so low and so cut into by great shallow lagoons, that it is difficult to define a coast-line at all. It is easy to see how this very remarkable area has been formed, the shore-reef spreading seawards rapidly in the shallow water, where its débris would be at once available as a substratum on which the growing zone of coral could advance seawards. Within the growing edge the accumulated mass of corals &c. would undergo decay and solution into the maze of reefs now found there; while others were being carved out of the low coast, and these, when their surfaces were covered with coral, living and dead, would become indistinguishable from those which had grown up *in situ*.

The Barrier System.

But little is to be added to the account given by Darwin in his 'Coral Reefs,' and for a description I refer to his work p. 102 & pp. 143–146 (the latter reference including a special section on the reefs between Suakim and Halaib), and to the map on p. 6 (*supra*). But the facts I have given above show that it is impossible to suppose a secondary subsidence of the

* Note added Sept. 1907.—On land the contrast consists in the absence of sandstone coast-hills, the significance of which will be seen after reading the following pages and the postscript.

middle part of the Red Sea in order to explain the occurrence of barrier-reefs on this coast. The absence of the regular barriers in the southern section is not a consequence of elevation; for the evidence is distinct that the recent movements have been the same here as in the north, but is rather correlated with the different slope of the sea-bottom, and probably, as will be explained later, with the structure of the sides of this part of the rift-valley.

That the latest movement has been one of elevation is shown by the character of the erosion-marks left on the cliffs, which include details which would be comparatively soon weathered away from so soft a rock, especially when one considers the important part played by sand-erosion on this desert coast. The very recent character of the fossils contained in the cliffs is evidence in the same direction.

The present form of most of these reefs is the result of the same processes as have formed those of Zanzibar and East Africa *, where the forces of erosion, with the aid of organic growth insufficient to add to the bulk of the material, have carved out all the characteristic forms of coral reefs. In the Red Sea, coral-growth is still adding greatly to the bulk of the reefs, but that the foundations of the present reefs are due to erosion the examination of the physical geography of this coast proves conclusively.

Ehrenberg, over seventy years ago, stated that the foundation of the Red Sea reefs originated in this way, but here the problem is more complicated than on the Equatorial coasts by the impossibility of distinguishing between that area of a reef which is due to the erosion of elevated coral-rock and that which has been added by recent growth, except in the case of some of the Khor Dongola (Dongonab) reefs, where such additions have not completely concealed the original foundations.

At first sight it seems most probable that these last-mentioned reefs are examples of the mode of formation suggested by Darwin† in the cases of the Farsan and Dahlak archipelagoes, viz. by the collection of sediment on an uneven bottom from which coral-growth took its rise. The Dongola Barrier (map, fig. 2, p. 15), indeed, seems an obvious case of this occurrence, the bank continuing awash for a long distance to the west of the sand islands, and the bottom in the neighbourhood being sandy with no very considerable masses of coral or nullipore growth. But a closer examination shows that this explanation, seemingly so plausible, is not correct, and that, in fact, the bank has a rock foundation merely overlaid by the sandbank and such coral-

* C. Crossland, "The Coral Reefs of Zanzibar," Proc. Camb. Phil. Soc. xi. p. 493; and "The Reefs of Pemba and the East African mainland," *l. c.* xii. 1902, p. 35.

† I confine my quotation to Darwin, as he is the only author who has described the reefs of this part of the Red Sea in general terms. The wider problem has been attacked by numerous workers.

For an epitome of recent views see J. Stanley Gardiner's paper "The Formation of Coral Reefs," in 'Nature,' Feb. 18th, 1904.

growths as occur *. In places, a strip of hard coral-rock showing *sections* of the contained corals and shells is left bare about water-level, below the sand of which the islets are composed, and this is true of most of the other sand islets in Khor Dongola.

I have seen no reefs of any importance, on the Sudan coast at least, which could have had banks of sediment, transported and deposited by currents, for their foundations. On a smaller scale, however, possible examples are those bounding the fine harbour of Mohamed Ghul, several square miles of reefs in the neighbourhood of the village of Dongola, and many of those described in the Shubuk area in the south. Such banks are only to be found in comparatively sheltered situations, never in the open sea around the Barrier system.

Below water-level a careful examination of the bottom shows, in many places, bare rock-flats usually thinly coated with mud. It is thus shown that the Barrier and other reefs of Khor Dongola have been merely carved out of the rock by the action of the sea.

The real Barrier system is even more easily seen to be formed by erosion.

The fact that the reefs between Makawa Island and the peninsula of Rawaya are the remains of a former land-connection between the two is almost obvious, especially as a remnant of this lost land remains as an isolated pillar of coral-limestone, 8 feet high, on "St. Fillan's Reef," nearly midway between the two. Although Makawa Island is high, about 500 feet will not be far from the mark, its southern end is little above sea-level. Similarly, Rawaya, though hills up to 200 feet in height are present, has considerable areas which must in course of time be reduced to reefs, so low are they. The neck joining it to the mainland is particularly low and narrow, so that Rawaya must soon become a chain of limestone islands connected by a complicated reef system indistinguishable from that now connecting it to Makawa Island. Similarly the Barrier system to the south of Makawa, perhaps as far as the Tiflah Islands, is a continuation of the Rawaya-Makawa hills, either as eroded remnants of the range or as submarine hills not yet elevated above sea-level. The latter must be true of the southern reefs, in which case the most likely postulate to account both for their growth and for the existence of other ranges of coral-capped hills *which are parallel to the sides of the rift-valley*, is that the faulting which produced it resulted in the sides being in the form of a series of steps or parallel ridges, upon which the remains of organisms would accumulate far more rapidly than on the intervening troughs or flats, so raising the ridges until corals, finally of reef-building species, could carry the ridge up to the surface comparatively rapidly †.

* From Mr. Stanley Gardiner's last report (in 'Nature') on the Percy Sladen Expedition in H.M.S. 'Sealark' (January 1906) it appears that the fringing-reefs of the Seychelles are another case where recent coral merely coats over older rock.

† J. Stanley Gardiner, "The Building of Atolls," Proc. Camb. Phil. Soc. 1902.

Further north is another prominent point, Ras Benas, which shelters a large bay and has a large island to the south, exactly in the same way as Ras Rawaya. So like, indeed, are the appearances of the two points that the same name, Makawa *, has been given to the islands in both cases.

The Jezira Ridge on Ras Benas corresponds to the high ground on Rawaya, and the Makawa of latitude 23° 50′ N. is obviously the continuation of this range. Similarly the southern continuation of the range is represented by the "Horseshoe Reefs," which still retains a fragment of the ancient island in the form of "a white rock" which "looks like a boat," below which this range ends in another set of reefs.

The third prominent point of this coast is at the mouth of the Straits of Jubal (leading into the Gulf of Suez), where the Zêt Hills run southwards into the sea, where they are broken into a chain of islands ending in that of Shadwan. The process of denudation has here made comparatively little progress. Few reefs exist except those fringing islands—and the islands are high *on all their areas*, *e. g.* Shadwan 990 feet, Jubal 410. But imagine denudation to have progressed to a far greater extent and to have cut down the smaller islands to sea-level, their foundations being at the same time preserved or added to by the growth of coral, and we see that the conversion of a range of hills to a peninsula, island, and chain of barrier-reefs becomes complete, as in the case of Rawaya, Makawa, and Tiflah. The repetition of this arrangement on this coast is striking, but just as some ranges are entirely inland (*e. g.* the Abu Hamâma range), so others are completely transformed to barrier-reefs, or perhaps were never elevated so high as to be continuous with the land, or even to project above the sea. For instance, the long reef, Shab Suadi, seems to be a continuation of the promontory of Salaka, but there are no hills in the vicinity that could be part of its range. The Barrier system *inside* Foul Bay, south of Ras Benas, is not connected with that point or its "Jezira ridge."

To the south this reef system bears the Mirear (lat. 24° 40′) and Siyal (lat. 23°) Islands and some small rocks, the islands being low and flat, only 6 to 12 feet above sea-level, and composed of elevated coral.

The Formation of Coral-Rag.

An instructive comparison can be made between the elevated coral of the Red Sea coast and that of Zanzibar. Both are low, and contain fossilized specimens of the species now living in the adjacent sea, and are consequently among the latest of geological formations. In both cases the alteration of the relative level of land and water has been effected in so regular a manner that the corals of the land retain relatively the position in which they grew when submerged. But in spite of these fundamental resemblances the physical properties of the rocks are as widely different as possible.

* This Arabic name, meaning "that which is resistant," has therefore a deeper significance than its donors supposed.

In one's mental photographs of the two coasts, the most prominent feature in either case is the black colour and fantastic forms of the Zanzibar coast rocks and the light yellow and usually formless characters of those of the Sudan. These are the outward visible signs of equally striking differences in their physical constitutions.

In Zanzibar and British East Africa the low cliffs are of an exceedingly hard crystalline rock, which is so homogeneous and tenacious that the overhanging shelf left by the undermining of the sea may, under favourable circumstances, project for more than four feet without its breaking down. The surface of the rock, both on the coast and inland, is, as already mentioned, almost black, though when broken the rock itself is seen to be white or nearly so. The raised coral of the Red Sea coast, on the other hand, is generally soft, often indeed like loose sandy gravel of shells and coral fragments with the larger coral colonies as embedded stones. The *bases* of the cliffs are somewhat harder ; and though their undermining results in forms which distinctly recall the cliffs of East Africa, the lack of homogeneity and cohesion of their material results either in a monotonous formlessness or, where somewhat harder rock occurs, the substitution of picturesque masses of fallen rock for the bizarre pillars, brackets and arches of the Equatorial coasts.

Although fossils are very abundant in the Zanzibar rock and are visible in section in the cliffs, yet the greater part of the rock near the surface is so homogeneous and shows so little trace of its origin from a loose conglomerate, that there would be great difficulty in separating such fossils as occur from the surrounding matrix.

It is important to notice, however, that in places at a little depth below the surface, the rock becomes much less crystalline and its fossils more easily separable ; in short, it approaches the condition of the Red Sea rock. From quarries made for road metalling, Mr. T. J. Last, Slavery Commissioner in Zanzibar, made large collections of fossils and their casts, and a whole series of stages in the crystallizing process could be easily obtained.

On the Sudan coast again the rock has the characters of that of Zanzibar in certain localities, *but only where the conditions to which it is exposed approximate to those normal on the Equator*; that is, to being " 'twixt wind and water " at the sea-level in places where it is under wave-action *.

The whole surface of Zanzibar is under such conditions owing to its heavy rainfall, but rainfall being practically nil on the Sudan coast we find the hardened crystalline rock only by the sea at water-level. Further, owing to the inappreciable tide, the reefs give constant protection to the cliffs' bases, so that only in exceptional places does one find coral-rock freely exposed to waves and spray. For some reason the reef is absent from the eastern cliffs of the islet of Tella Tella Kebira, which are therefore almost constantly bathed in spray, and have taken on all the characteristics of the Zanzibar rocks, in

* See also the preceding paper on the coast near Alexandria.

marked contrast to the other islets in the vicinity, which have only the usual partial hardening of the undermined portions of their cliffs.

In Khor Dongonab, where protection of the coast by coral is less complete, the foundations of the sand islets is, as already mentioned, of coral-rock, and at sea-level, where it is alternately wetted and dried, it has taken on the typical qualities of "Coral-Rag." In the same way, beach sandstone has in several cases been formed by the cementation of the sand of which the islets are composed, and this is as hard as the coral-rag where it overlies it, becoming softer and softer as it rises above the water-level till, at a height of 3 feet or so, it becomes of a crumbling consistence and passes into the loose sand from which it is derived. (See Pl. **1.** fig. 3 and its explanation.)

The facts cited certainly warrant the conclusion that the alteration of the Zanzibar rock from the mass of more or less loose material, in which condition it was elevated from the sea, to its present crystalline state, and that the rock of quite similar origin in the Red Sea has remained nearly in its primitive condition, is due to the absence of rain and generally of wave-action and spray in the latter region. The details of this action of water have not been worked out, but probably a recrystallization of the calcium carbonate and a partial substitution of magnesium, or dolomitization, occurs, both of these processes tending to harden the remaining product.

Conclusions.

The conclusions to be drawn from the above may be summarized as follows :—

1. That the coast of the Sudan, besides its major elevations amounting to more than 1100 feet, has recently undergone several small elevations, the movements having been uniform in their action and not recently reversed.
2. That the differences between this elevated coral and rock of similar origin elsewhere, *e. g.* on the coast of Equatorial East Africa, is due mainly to the absence of tide and rain in the Red Sea.
3. That the present form of the reefs is due as much to the eroding action of the sea upon this elevated rock as to the growth of corals.

   In the case of *Fringing-Reefs* (including the Shubuk area) the land is cut down to sea-level behind the rim of growing coral. *Barrier-Reefs* are formed: (1) By the direct growth of coral upon submarine hill ranges; the northern ends of these have been elevated, and are now ranges of coral-capped hills, the middle parts remain as peninsulas and islands, the southern as Barrier-reefs. (2) By the cutting down by marine erosion of promontories and islands, and of coral-reefs previously elevated.

Postscript.

As the theory of the Barrier Formations here advanced turns on the structure and topography of the coast hills, I give the information I have been able to collect.

The hills are not distinguishable on any map, indeed part of the country is, as yet, unsurveyed, and I have had few opportunities of travelling inland. My account is therefore incomplete, but enough has been done to justify the conclusions drawn.

From seawards these hills are easily distinguished from the jagged hills of igneous origin by their cliffs being of a light yellow colour and by their flat tops; generally also by their position being nearer the sea than the lowest of the igneous hills, and even than the mounds of gravel which occur in places at the foot of the latter.

Passing from South to North, the first range is met with a few miles north of Mersa Durur (see map p. 6) as a chain of low butts rising from the alluvial plain four or five miles inland. These become higher and more continuous as one passes northwards till they end in two considerable hills, of about the same height and area of base, the northern of which is marked on the charts, where it is called Table Mountain and given a height of 1100 feet.

At about five miles inland from Dongonab are one or two small hills standing alone, but further north is a range of higher hills lying inland from the middle of the North Bay and extending towards the Hamâma range, from which it is only separated by an interval of a few miles.

The Abu Hamâma * range (which I so named from its most prominent though not highest peak, a famous landmark for sailors) extends from around the inner branches of Khor Shinab to some distance beyond Khor Abu Hamâma, lying much nearer the sea than do the above. Its height is estimated by the Government Surveyor at from 500 to 700 feet.

These ranges are wholly inland, rising abruptly from the maritime plain, which they divide longitudinally. I have not been able to see whether they are coral-capped, but have seen that their bases, at least, have the structure of the range next described.

The hills of the Rawaya Peninsula and Jebel Makawa form an outer range parallel to the above, and are capped with a stratum of modern corals. They were once barrier reefs, growing upon sandstone foundations.

The highest points of the Rawaya peninsula are near its north end, and eastwards from the salt-works in the south, the northern being an extensive plateau of a height of about 100 feet. the latter a hill of about twice this

* This may be translated "Pigeon Hill," and is so called from the curious shape of its summit.

height. The rest of the surface is low or undulating, generally about twelve feet above sea-level but in many places very little above the sea.

The outline of the peninsula as given on the chart is only approximately correct; it is broken up by many intricate "Khors" or inlets of the sea, of which "Khor Rawaya" is but one.

A section of the Northern plateau is given by a cliff about 60 feet high which borders a fault, now full of sea-water, known as Khor Atôf. The drawing given (Pl. 4) shows its structure, which is typical of the whole of this peninsula. Above is a mass about six feet thick of recent corals (A), all in the position of growth. The large numbers of shells which accompany these are still more easily identified as being of living species.

Next is a thicker stratum apparently of consolidated coral-mud (B & C), containing two characteristic fossils, nullipore nodules and a clypeastrid echinoderm. The latter occurs in large numbers and is easily recognized as a species still living in Khor Atôf.

This is all the reef formation present*. Below it is a bed of gypsum (D) of varying thicknesses up to 12 feet, this resting on a finely laminated and very soft sandstone (E), generally yellow in colour but here often dark green or red.

The coral formations are in horizontal strata, *and are unconformable to the strata on which they rest*, which are considerably folded and contorted.

In the lower parts of the peninsula, the coral stratum is thicker, *e. g.* at Haysoit Island up to 15 feet are exposed, the coral-mud and other strata not appearing above the sea-level. The hill in the south (Jebel Abu Shagara) is similar, forming a great cliff bounding the fault in which lie two inlets of the sea, "Khor Rawaya" opening northwards, and Khor Abu Shagara which runs in from the open sea, *i. e.* from the south. The view eastwards from the summit is striking, the peninsula here consisting of a series of parallel ridges and troughs, the result of smaller faults, some of which contain sea-water inlets. These, like all the Khors above named, run approximately north and south. Jebel Abu Shagara is itself cleft by a great north and south gash in its southern part, which may be taken as one of the coast inlets elevated above the sea for our examination. It shows the same structure as the cliff on the east side, viz., a shallow cap of coral underlaid by gypsum and sandstone as in the north, but here the gypsum band is narrow and may be absent, the sandstone in any case forming the great bulk of the hill. This rock forms also the bulk of the islands of Makawa and Mayiti, which are about 500 and 300 feet high respectively. I have not climbed Makawa, but Mayiti is coral-capped. The east side of all these hills is precipitous, the west sloping.

* I have found no elevated reefs thicker than 15 feet on the Sudan coast. This agrees with the accounts given of those of both shores of the Gulf of Suez and the Sinai Peninsula.

This chain of hills, it is evident, were once islands and submarine banks lying parallel to the coast, their formation and position being a mechanical result of the opening of the rift valley. By marine erosion and the growth of Corals, these became levelled down and built up to a line of barrier reefs, part of which has now been elevated above the sea-level as the coast-ranges and as islands, other parts being elevated to such heights that rapid coral-growth has been possible on their summits. The deeper portions have probably been raised to within the limits of growth of reef corals by the accumulation upon them of the remains of marine organisms, which flourish especially on any elevation of the sea-bottom in the way described by J. Stanley Gardiner*. Thus, by degradation of the parts above sea-level and aggradation below, are formed the level lines of reefs of the barrier system of the present day. This mode of formation is probably the origin of the level band of coral-rock which lies between the alluvial gravel of the maritime plain and the deep sea, and to the presence of which this plain, consisting as it does of large gravel and sand to great depths, is due. (See p. 14, note at bottom of page.)

Sept. 20, 1907. CYRIL CROSSLAND.

EXPLANATION OF THE PLATES.

PLATE 1.

Fig. 1. A pearling canoe and its occupants.

2. Diver returning to the canoe with a captured pearl-oyster.

3. Beach sandstone on the island of Sararat, in Khor Dongonab.

(*a*). Sea horizon.

(*b*). Hard coral-rock, eroded down to sea-level, which forms the foundation of the sand island and of the adjacent living reefs.

(*c*) to (*e*). Band of beach sandstone, smooth and hard at (*c*), rough and moderately hard in the dark band, very soft at (*e*).

(*f*) is the loose sand of which the island was originally composed entirely.

4. Mouth of one of the shallow valleys which drain Rawaya and open into the North Bay. The opening lies between two low cliffs of coral-rock, one of which is shown in the background of the photograph. During the winter, fresh water percolates through the sand of the valley, which it consolidates into beach sandstone where it meets the sea-water. At A the sandstone has a smooth surface, at B broken and apparently undergoing reduction by the sea. This sandstone is found in all the valley mouths in this bay.

Figs. 5 & 6. Part of a large heap of old pearl-shells which forms a considerable part of the island of Umm es Shekh, the Holy Island of Khor Dongonab. Presumably these are the remains of fisheries made in the days when this species was fished only for its pearls, not as now mainly for the mother-of-pearl shell. Needless to say their value, which would be very great if the shells were fresh, is now nil.

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* "The Building of Atolls," Proc. Camb. Phil. Soc. 1902.

PLATE 2.

Fig. 1. General view of the cliffs eastwards of Alexandria. The rocks in the foreground are made of rubble consolidated by the sea, the similarly situated reef in the middle distance is natural sandstone.

2. Hill of rubble at Chatby, Alexandria, remaining after the surrounding land has been excavated to its original level.

3. Portion of cliff face situated between 2 and 1 above. The upper part of loose rubble containing pottery, &c.: the lower of very soft sandstone.

PLATE 3.

Fig. 1. Catacomb passages exposed by the sea, in the same locality as above. The cliff is coherent sand below, rubble &c. above, as in Pl. 2. fig. 3. Eight niches for bodies can be made out in the foreground, to the left of the main passage.

2. The "Spouting Rock" beyond Palais station, showing the regular shelf surrounding the rock just below water-level and partially laid bare during the retreat of a wave.

PLATE 4.

Jebel Têtâwib, in Khor Dongonab, a butt near its southern extremity, seen from its south side. The letter B is at a level about 25 feet above the foreground.

A. Coral colonies, in position of growth, bedded in a mass of loose coral débris, shells, &c.

B. Corals bedded in consolidated coral-mud, forming a harder layer than that formed by either constituent alone and so projecting shelfwise at B. This layer passes gradually into C.

C. Hardened coral-mud. The weathered surface forms rounded masses in low relief.

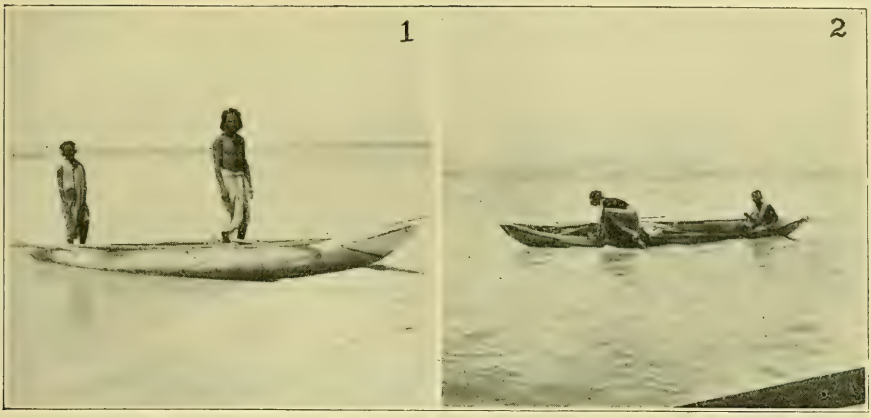
D. Gypsum strata, here steeply tilted, and upturned at their ends in the piece shown in the foreground. They are much folded in other parts of the cliff.

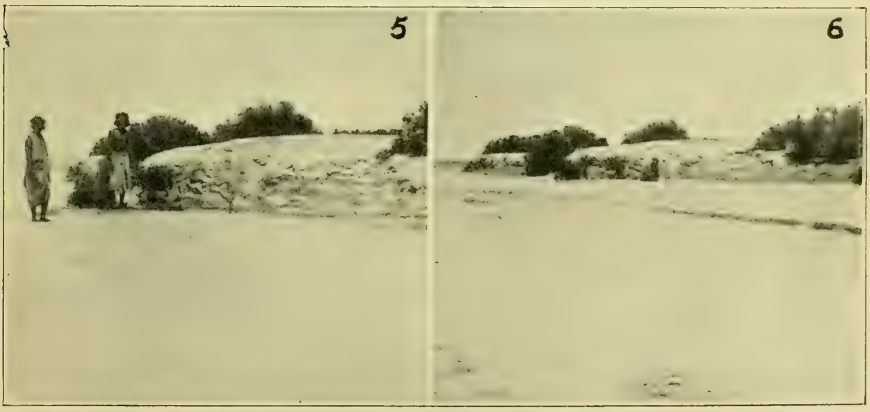
E. Green and red shaly rock underlying and sometimes interstratified with the gypsum. It is here broken down into sand. This rock contains sheets of glass-like recrystallized gypsum.

F. A fallen piece of B. Contrast its roughness with the smooth rounded surfaces of C upon which it lies.

G. Scree material from A & B, consisting of coral and shells.

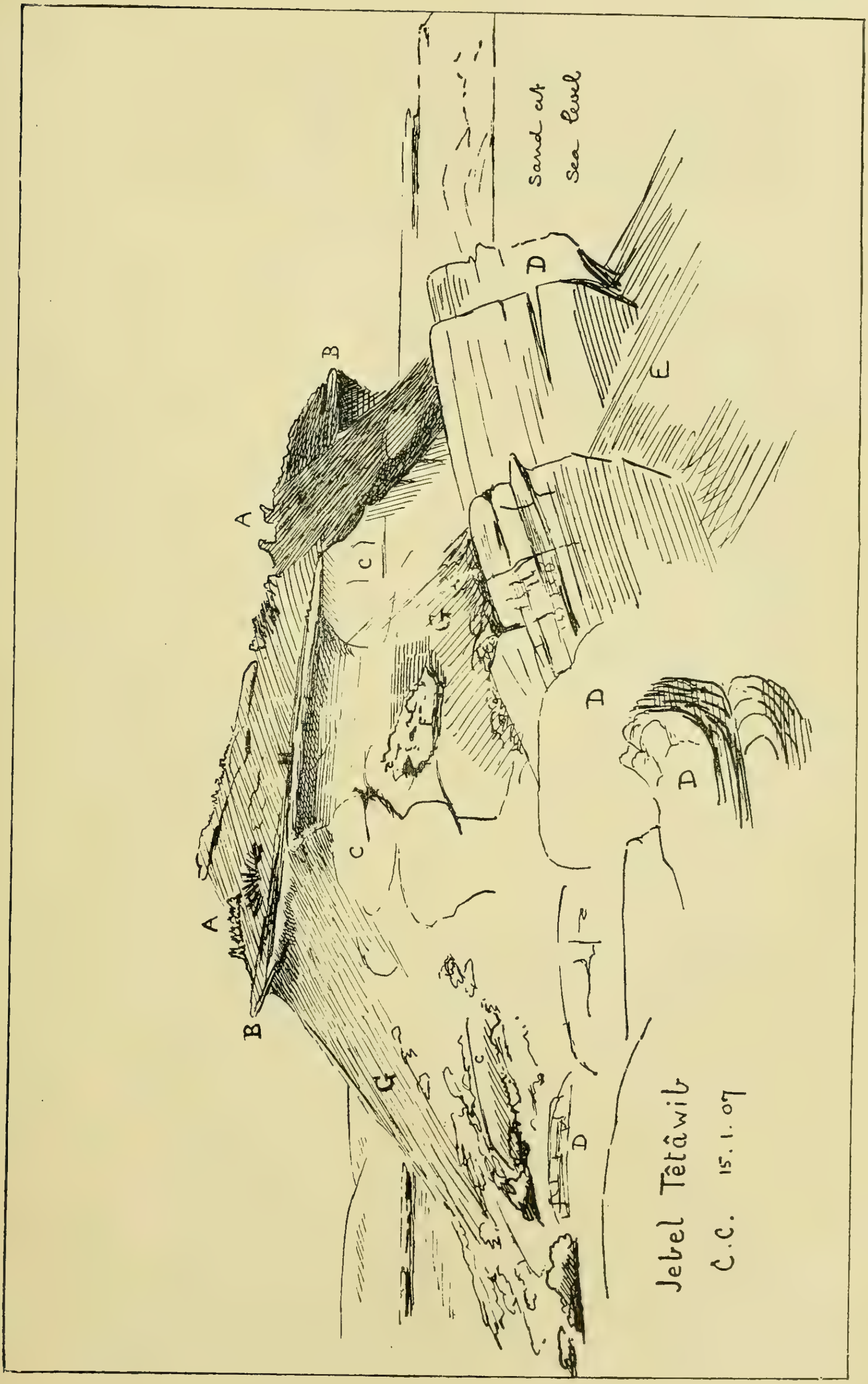
H. A dark line of reddish broken shell-material, containing many *Cidaris*-spines. This is more prominent in some other parts of the hill.





C. C. Photo. Grout, Engr.

SCENES IN THE RED SEA.


Sand at
Sea level
Jebel Tetâwib
C.C. 15.1.07